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AN INTEGRATED APPROACH TO TEACHING ELECTROACOUSTICS AND ACOUSTICAL ANALYSIS TO MUSIC TECHNOLOGY STUDENTS

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There is a requirement for Music Technology and Audio Engineering students to understand theoretical concepts along with acquiring practical experience in areas covering electroacoustic devices, room acoustics and measurement techniques. Traditionally, room acoustics is taught under an assumption of a high level of mathematical knowledge by the student, however, in this paper, an alternative, integrated practical approach to teaching is presented covering these discipline areas which has led to enhanced cross-curricular skills, improved student experience and increased learner attainment. The aim was to develop students' higher-level cognitive domain skills through active experiential learning. The students captured room impulse responses and assessed their subjective qualities within a convolution reverb and from an acoustical analysis platform. Results show a general preference to experiential learning and an integrated cross-curricular approach within undergraduate study.

AUDIO ENGINEERING: A MULTI-DISCIPLINE ENGINEERING FIELD

Many innovative instructional methods have been developed for technical courses, and many described for use in engineering but not specifically for Music Technology or Audio Engineering. For the purposes of this paper, the term *audio engineering* will be used to describe music technology, sound engineering and production, audio engineering and acoustics.

A review of current audio engineering degree programs shows disciplines such as acoustics, audio systems design, broadcast engineering, computer science, electroacoustics, electronics, IT and network technology, mathematics, and recording arts for example, being taught in a single 3 or 4 year program. Industry standards from many organizations and governing bodies such as the AES, EBU, ISO, IEEE and SMPTE are incorporated within many of these curricula. Although many current programs within the UK, Europe and America do specialize in their own areas and domain, there is still a requirement for a broad range of discipline areas to be covered within a degree program. Courses, curriculums and single modules of study can be cluttered with disparate disciplines [1] and incompatible topics for integration, thus necessitating the integration of comparable disciplines.

With regard to the problem of designing curriculums to include the ever-increasing number of specialty areas within engineering and specifically audio engineering, one solution is that emphasis shifts from providing training in all specialty areas to teaching a core set of science and engineering fundamentals, helping students integrate knowledge across courses and disciplines [2].

It is the opinion of the authors that acoustics, acoustical analysis and the fundamentals of electroacoustic device measurement and application are compatible disciplines for such knowledge integration.

The purpose of this paper is to describe an approach to the integration of the aforementioned disciplines and describe appropriate pedagogical instructional methods to meet the following criteria for audio engineering education chosen and according to [3]:

1) They are relevant to audio engineering education.

2) They can be implemented within the context of the typical audio engineering classroom.

3) Audio engineering educators should be able to implement them.

4) They are consistent with modern learning theories and have been successfully utilised by audio engineering educators.

1 CURRICULUM DESIGN

Within the School of Engineering and Computing, the BSc (Hons) Music Technology program uses the Module COMP08007 Electroacoustics to integrate 2nd year undergraduate learning in electroacoustics and acoustical analysis. Previously the module, under a different title, failed to contextualize theory, used formal examination as a main assessment method and subsequently performed poorly in terms of student attainment. This revised module uses a project-based learning approach and its main purpose is to provide a mechanism for students to apply modern techniques in electroacoustic and acoustic measurement, develop a practical knowledge of important physical parameters and an understanding of room acoustics. Thiele Small parameters and acoustic intelligibility parameters are not discussed here, as they are introduced at a later stage of the Music Technology program.

Electroacoustic device parameters such as frequency response and distortion were measured and assessed in two different environments, (an anechoic chamber and a recording isolation booth), and their importance [4] contextualized within the study of room impulse response (RIR) capture and acoustical analysis [5]. Stereo microphone techniques [6] were employed for room reverberation capture and for simulation suitable for reproduction through a normal stereo system (2-loudspeakers). Practical room acoustics analysis was achieved through RIR capture, using a mono (omnidirectional) reference microphone towards an acceptable level of measurement accuracy [7].

Room acoustics basic theory was presented to facilitate the theoretical design of a studio control room and underpin the acoustic analysis element of the Module.

From the devices under test (DUT) and their parameter evaluation, students then selected the most appropriate microphones and loudspeakers to perform impulse response (IR) capture. Room Impulse response (RIR) capture was performed in various acoustic environments and acoustic analysis was performed in three studio control rooms.

1.1Curriculum Objectives

To best serve future audio engineers, as educators, we have a responsibility to ensure (and enhance) the quality of audio engineering education by designing curricula that develops the intellectual skills and capabilities of graduates using common language and a common level of technical understanding [8]. It is reasonable to propose that the constant evolution of audio engineering hardware and software necessitates the need for solid underpinning of audio engineering fundamentals.

Required professional competencies will be directly discipline related such as the use of specific software and hardware, data acquisition and analysis, technical writing, and a knowledge and application of relevant and current industry standards. The following are offered as general curriculum objectives, which may be applied to undergraduate audio engineering modules or study programs:

1) Integrate multiple disciplines.

2) Present theory that can be readily contextualized.

3) Promote the importance of industry standards.

4) Develop professional practice.

1.2 Educational Objectives

Other competencies for audio engineers include communication skills, teamwork and collaborative thinking, life-long learning skills, and computer literacy, which are developed through innovative educational methods.

The following are, again, offered as general objectives:

1) Engage and motivate students to learn.

2) Create an active learning environment.

3) Develop higher-level cognitive domain skills.

4) Promote the importance of research.

5) Develop self-directed, life-long learner skills.

2 INSTRUCTIONAL METHODS: DEFINITION

For undergraduate study in engineering, and specifically audio engineering, there is a requirement for the development of higher level cognitive skills [9]. These higher level cognitive domain skills can be developed through experiential learning with the implementation of Problem Based Learning (PBL) strategy theory as a framework with which to design the appropriate instructional methods in accordance with the epistemology of the disciplines. Instruction should facilitate domain specific knowledge acquisition that can be supported by human cognitive architecture [10].

Within the curriculum design, one aim was to develop students' awareness of thinking about their own learning. This self-metacognitive activity (higher level cognitive knowledge) [11] is attributed to the ability to self-learn and therefore important for current and future audio engineers.

Bloom's Taxonomy of Learning motivates deep learning among students and is fostered through learning activities featuring instructional techniques: problem-based learning, cooperative, and collaborative learning. These six cognitive levels are: (1) knowledge, (2) comprehension, (3) application, (4) analysis, (5) synthesis, and (6) evaluation. Educators now realize the importance of addressing all levels of the Taxonomy from early on (lower levels) in the curriculum [9].

As a general rule, the first three cognitive levels can be mapped into the lower levels of the Music Technology curriculum (year 1 and 2 of the 4-year program) and the three upper levels map into the higher levels of the degree curriculum in accordance with The Scottish Credit and Qualifications Framework (SCQF) [12].

The SCQF describes the Levels 7,8,9 and 10, where level 9 equates to ordinary degree level i.e. Bachelor of Science (BSc) and Level 10 crediting a 4th year level of study at Honours (BSc Hons). The module described in this paper is at SCQF level 8 (comparable European Qualification Framework level 5) and has a value of 20 SCQF credits (10 ECTS credits).

Blooms taxonomy of learning, due to its simplicity to understand from a learner perspective, provided the basis for a discussion with the student groups as to the module delivery, assessment grading and how the levels map to the teaching and instructional methods they would encounter. It has long been established as an accurate language for creating standardized assessment criteria and was used to:

- Describes a student's performance growth.
- Define curriculum level objectives.
- Assess student's performance and justify grading.
- Provide feedback to student's performance.

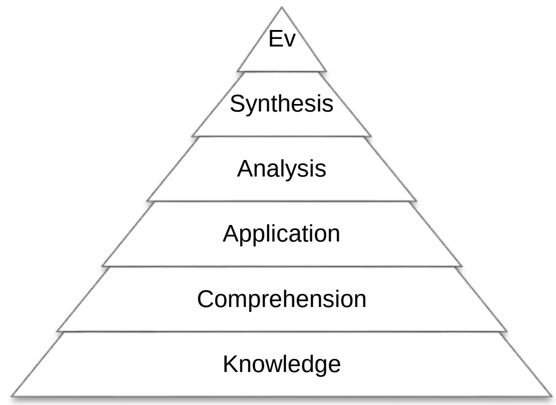

Figure 1 – Bloom's Taxonomy of learning

It has been the authors' previous experience that at the beginning of a module of study, the student group are aware of the teaching and learning goals, the instructional methods to be used, their associated benefits, and assessment feedback mechanisms. In other words, an agreement (understanding) is made between educator and student on the learning and assessment methodology.

2.1 Instructional Guidance

There are several reasons why the minimal guidance approach does not work [13] and an appropriate amount of instructional guidance is required. This paper puts forward the recommendation that appropriate *guided discovery* [14] will promote active learning and yield efficient learning without any of the disadvantages which can be incurred from a minimal guidance approach.

Within the context of this paper, the introduction of problem-based learning elements were chosen in relation to the intermediate level of academic study. It is reasonable to say that experiential learning may be used with appropriately designed discovery-learning tasks with guidance and additional support when required.

2.2 Collaborative Learning Theory (CLT)

Learning environments that facilitate collaborative learning produce efficient learning with high-complexity tasks by expanding cognitive capacity and the distribution of cognitive load across a working student group [15].

2.3 Project Based Learning

Project based learning has long been established as a pedagogical method for structuring traditional engineering curriculum for the four main engineering disciplines, mechanical, civil and construction, electro and chemical [1]. The motivation for the use of project-based learning as a core method for the curriculum presented in this paper is mainly derived from the relationship between project-based learning and professional reality; professional skills development through the application of knowledge [16]. It can accommodate the use of group-work which facilitates collaborative (peer) learning in which students share their skills to achieve a common goal. In order to engage and motivate students to learn, there is a requirement for educators to provide stimulating and interesting tasks, activities, and materials where novelty and variety are included [17]. This can be achieved through designing effective group-based projects, the implementation of varied instructional methods and the use of different learning environments.

2.4 Problem-based learning

Experiential learning or the *minimal guidance* approach is also termed as problem-based learning, discovery learning or inquiry learning. This paper suggests that the approach of *pure discovery* does not favor learning efficiency and should not be utilised when educating novice learners [12, 13]. Guided discovery through a problem-based learning (PBL) strategy will ensure students construct the 'right' knowledge [16]. PBL may be introduced to intermediate and experienced learners. Where learner knowledge and experience increases, the level (amount) of instructional guidance can decrease. Experiential learning gives active learners more control and autonomy therefore intrinsic motivation [18].

Higher-level cognitive domain skills, according to the selected taxonomy (4) analysis, (5) synthesis, and (6) evaluation, are developed through *guided* discovery learning. These can be developed through the design of specific project tasks where experiential learning will take place.

3 INSTRUCTIONAL METHODS: IMPLIMENTATION

When integrating disciplines and topics, multiple instructional methods and approaches may be required to meet the varying levels of student aptitude. The implementation of *minimally guided* PBL approaches must be monitored and evaluated with regard to learning efficiency (learner progression). Integrating appropriate instructional methods such as Project-based and Problem-based learning in a Project-organized Problem-based learning (POPBL) format is a proven method within masters study programmes in acoustics [19]. The authors have implemented a similar approach to this undergraduate curriculum with two, short- term projects being designed for SCQF Level 8 (year 2) students.

3.1 Collaborative learning

Each group was given the task to produce, on paper, a design for a microphone detailing the main electroacoustic device parameters, including logarithmic frequency response and polar graphs, its application and feature set. This involved a review of current microphones, understanding and reading specifications, contextualized through anechoic microphone tests undertaken, and concluded in the form of presentations to class peers. No grade was attributed to this work and it was observed that student self-direction, with CLT, provided motivation, produced efficient learning and promoted debate and discussion between students.

3.2 Project Based Learning

Student group allocation was done by educator selection ensuring a broader spectrum of individual attributes within any one group. Promoting teamwork and communication skills development requires group members to work together for at least a period of a month [14]. Mid-point of the curriculum delivery allowed for groups to disband and reform, however, this was not necessary with the cohort. (Group size: 4)

Two small projects running for 5 weeks each (10 hours of practical application allocated to each) were designed with POPBL approach implementing experiential learning: 1) *Room Impulse Response Capture: Room Space Simulation* and 2) *Room Acoustic Analysis and Design*. The projects formed the basis for the problem tasks to be resolved by the student groups.

The following tables show the 2 projects broken down in to smaller tasks with the amount (level) of instruction given:

3.2.1 Project 1

Table I RIR Capture: Room Space Simulation

Task	Description	Guidance
1	*Test Environment Assessment*	Instructional
2	*Device Measurement*	Instructional
3	*IR Capture*	Minimal
4	*Room Simulation Reproduction*	Minimal

Tasks 1 and 2 were carried out with *guided instruction*, where analysis was carried out using a reference microphone (omnidirectional) in a number of locations and averaged to give a final frequency response and reverberation characteristic such as Early Decay Time (EDT), T_{20} and T_{30}. Students evaluated the analyzed test environments and their suitability for critical measurement of electroacoustic devices. The measurement microphone and system software was calibrated to a sound pressure level (SPL) reference of 94dBSPL [20], [21] (equal to 1 Pa) (A-weighted) with a 1 kHz tone provided by an NC-74-002 Sound Calibrator.

A number of loudspeakers and microphones were offered to the groups and a selection of 3 of each was made for measurement. Loudspeakers were measured for frequency response (FR) characteristics through IR capture and Total Harmonic Distortion (THD) through Real-time Analysis (RTA). The same reference measurement level was chosen for both loudspeaker and microphone measurement. Microphone parameters such as sensitivity are normally measured with the acoustic input reference level of 94dBSPL [22]. A system input gain calibrated to the reference level with a 1kHz sine wave tone generated for THD with RTA, and measurement of impulse response with a swept-sine technique [23] providing Time Frequency Analysis. Ninety five dB SPL (and above) is specified in [24] while testing towards the upper limit of loudspeaker capability.

The speakers under test were from different manufactures thus providing a range of designs, driver dimensions, differing frequency reproduction and harmonic characteristics, allowing realistic comparisons to be made by the students. Microphones were measured for frequency response only, where the equipment selection criteria for *Project 1* “IR capture for room space simulation and reproduction” was based upon device linearity.

The resultant graphic-numerical data allowed the students to contextualize electroacoustic device theory through practical parameter measurement and evaluation. From evaluation, the most appropriate electroacoustic equipment for IR capture was selected.

Task 3 and 4 were achieved with *minimal guidance*. A pair of previously tested high quality cardioids in ORTF configuration [6] were used with Apple IR Utility software [25]. Student groups initially captured a stairwell, a corridor and a lecture theatre and an assessment of Impulse to Noise Ratios (INR) was made according to [7], [26] prior to post processing of the file. Impulse response energy graphs provided numerical data between the impulse transient peak and the noise floor which allowed assessment of the INR i.e. 35 dB of headroom for acceptable levels. Using Logic Space Designer plug-in [27], sourced anechoic recordings were used to evaluate the subjective quality of reproduction in terms of spatiality, clarity and noise floor.

3.2.2 Project 2

Table II Room Acoustic Analysis and Design

Task	Description	Guidance
1	*Room Mode Prediction*	Minimal
2	*Room Mode Analysis*	Minimal
3	*Room acoustics analysis*	Minimal
4	*Room acoustics design*	Minimal

Within Task 1, as an example of PBL in the context of the curriculum, students were required to investigate (with *minimal guidance)* the relationship between room ratios (dimensions) and room modes. Initially students evaluated different available room mode calculators. Room dimensions were given for conversion to a suitable control room shape, where appropriate ratios were to be selected with regard to desired room modes spacing (Bonello criterion).

Task 2: In groups, with *guided instruction*, students performed Sine sweeps (20Hz - 200Hz) to excite room modes within the 3 control rooms, enabling correlation with the predicted modes from task 1. Within this practical approach, students are able to make the connection between room mode theory and the physical implications of standing waves in a critical listening environment, leading to a higher level of understanding. In particular, an untreated control room was used to demonstrate the method and process to the student groups for subsequent acoustic analysis.

Task 3, with *minimal guidance* students undertook full-spectrum sweeps of the control rooms to assess reverberation parameters. The methodology and results analysis were for inclusion into the second project report.

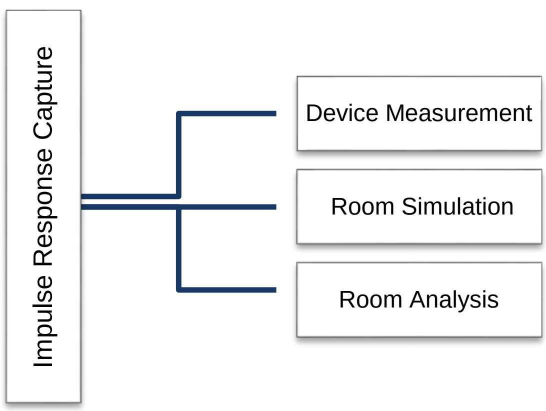

Figure 2 – IR Capture: Practical applications

Task (4) required work on an individual basis proposing a control room design including: room ratios (dimensions), construction and treatment methods, final RT calculations and as mentioned, a method for acoustic analysis. Within the submission, was the requirement for detailed speaker positioning for surround sound applications based on ITU recommendations. This final task was carried out with no guidance, however *supported guidance* was on an individual basis when required.

4 ASSESSMENT METHODS AND OBJECTIVES

The main assessment method was in the form of two document submissions (1 for each project). Both were designed to take 5 weeks to complete and students were encouraged to keep laboratory notes throughout. Two small e-assessments (mid-point and end point of curriculum) were used via the University virtual learning environment (VLE) (Moodle) to facilitate varied assessment methods and provide a mechanism for instant feedback on academic performance and their knowledge and understanding of the two distinct taught elements.

Table III Program Assessment Schedule

Week	Assessment Format	Grade Weight
5	Project 1	40%
6	E-assessment 1	10%
11	Project 2	40%
12	E-assessment 2	10%

Assignment (Project) 1: a standard engineering lab report in the form of Title, Abstract, Evaluation, Experiment, Results and Conclusion was the basis for the first written assessment.

Assignment (Project) 2: a technical design proposal, with plan diagrams, graphs of derivation between reverberation time and frequency with suggested room analysis method.

On completion of the module, it was intended that students were able to:

- Work within the safety guidelines and rules that apply to HSE noise exposure limits within a laboratory and external practical work.
- Account for the industry standards for: studio control room design in terms of ITU recommendations and develop an applicable knowledge of standard practices for acoustic and electroacoustic measurement.
- Perform practical electroacoustic and acoustic measurements and calculations related to basic (and complex) laboratory work and prepare solutions.
- Document and present laboratory and practical work through results, conclusions and evaluation.

5 LEARNING AND TEACHING RESOURCES

5.1 Literature Resources

Lecture presentations were given with supporting notes on microphones and loudspeakers and measurement techniques. Device specification sheets for each DUT were used to compare the student testing results against the stated manufacturers' data. This formed the basis with which students evaluated the testing regime in terms of accuracy and validity.

Instruction manuals for the software were provided by the manufacturers (Apple IR Utility and Room EQ Wizard) and as supporting documents including usage and technique, were viewed as substantial in scope, user application focus and of a suitable technical language for the module and level of study. A core text book [28] was used as the basis of read material for acoustics theory.

5.1.1 Undergraduate Research

At this level of study, student research of a high academic level is not expected, however, students were made aware of research within the discipline areas described in this paper. Undergraduate study into room ratios and acoustic design was based upon the original work of L.W. Sepmeyer [29] and M.M. Louden [30] for example, and the work of Angelo Farina [6, 20] in the field of impulse response capture was discussed and reviewed in basic form.

5.2 Software

The practical project outcomes required; electroacoustic device measurement, RIR capture and reproduction and acoustical analysis. Industry recognised software that was easily accessible was chosen rather than research type software written to perform novel work and which could yield inaccurate or unknown output [31]. After a review of available software, the student group chose Apple Impulse Response Utility, Apple Logic [27] and Space Designer (as the Convolution replay plug-in).

The authors' selected Room EQ Wizard (REQ) [32] as the device measurement and room acoustic analysis software in order to focus on the theory, processes and techniques within the curriculum and to bridge between the 2 projects. It was also specified as it is an open, free resource software enabling students to learn and experiment flexibly. Both applications operate under Mac OS, therefore ensuring system compatibility when switching between both. (REQ is dual platform; OSX and Windows).

Although the apple software is integrated with respect to creating IR pre-sets for reproduction, Space Designer will accept any de-convolved 24-bit IR wave file. In conjunction, the acoustic analysis software will accept and import any de-convolved RIR wave file for analysis. The ease of integration between the software was deemed non-restrictive and posed no barrier to student learning and achieving the important objective aspects of the projects.

Within the second assessed element of the module, the focus is on room acoustic design and analysis. The student group again reviewed software for room mode calculation available on-line. Amroc-The Room Mode Calculator [33], java based software, was chosen over simpler spreadsheet calculators for its' graphical representations of the relationships between room ratios, room modes, tones, Bonello Criteria and the Bolt Area.

5.3 Hardware

According to Adrian James [34], the use of a dodecahedron speaker is not crucial to the analysis of a room where Reverberation Time (RT) and Early Decay Time (EDT) measurements will not be affected by the directivity of the source speaker as long as it produces a sound pressure level sufficient to provide decay curves with the required minimum dynamic range (without contaminating background noise) [7]. As the testing was non-commercial (non- critical), the students selected the most suitable loudspeaker from their data gained at device testing stage. As described previously, equipment was selected due to its relative linearity and output level capabilities. Blue Sky studio monitors as source replay and Behringer ECM 8000s were used as reference microphones with AVID A/D convertors to interface to computer software. Two identical systems were available to the student groups. Calibration files for the audio interface were created and files for the microphone were sourced ensuring a higher degree of data acquisition accuracy.

5.4 Physical Environment

The acoustic characteristics of the two test environments were determined prior to conducting the initial practical element of the project. A subjective assessment of their effects on the electroacoustic device testing was of importance to the evaluation and reflection element of the student assessment. The two different measurement environments would allow a direct comparison between results taken by identical measurement systems.

The practical element of the curriculum was delivered with one main educator and one demonstrator in assistance, which allowed for multiple student groups in multiple areas carrying out simultaneous, supervised measurements. The Music Technology Laboratories house a total of 40 Apple computers with the required Apple software allowing student groups open access to project materials. The use of studios was open and the use of the anechoic chamber was supervised.

5 CONCLUSIONS

The student cohort reviewed and evaluated the module in terms of curriculum and resource satisfaction through generic paper based and peer review group methods. The module scored highly in terms of student satisfaction with positive comments on the RIR capture in the University Module Evaluation Questionnaire (MEQ).

Further questionnaires relating to this paper requested the students review their work in terms of motivation and learning and group size preference for both problem-based and project-based work. These additional questionnaires were completed by 20 students.

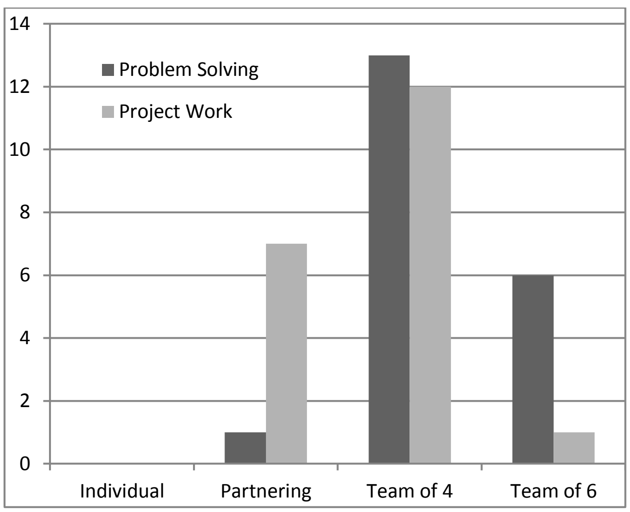

Figure 3 – Group size preference

In terms of group (team) size, it can be seen from the graph in Figure 3, that the student group had a preference for larger teams for problem solving (sharing cognitive load) and smaller teams (also partnering) for project work. It is noted that no student wanted to work as an individual.

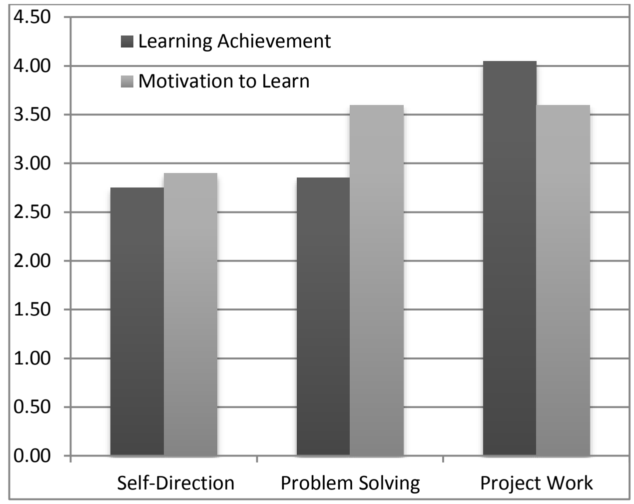

Figure 4 – Student Motivation and Learning

Results show the student group was of the opinion that they were significantly motivated by problem solving and project work, and learned the most from project-based tasks (experiential learning). There is a direct correlation between motivation and perceived learning achievement.

The use of differing environments and the understanding of physical influencing factors when conducting electroacoustic device measurements and/or room acoustic impulse response capture and acoustic analysis were well received by the student group. Twelve of the 32 that attended the module elected to carry out extracurricular work in RIR thus proving that motivation to continue to learn and utilize new skills was achieved. As regards future work for students, it is intended that they will create their own libraries of IR's for music and audio post production.

It is the view of the authors that these results show a general preference to experiential learning and an integrated cross-curricular approach within undergraduate study.

Although this paper does highlight some of the issues in designing audio engineering education, and provide one solution for discipline integration, it is recommended that further studies be undertaken into curriculum design for audio related programs that meet the need of future audio engineers for the next decade where undoubtedly advancement in mobile technology and computer literacy skills will be key to successful graduate employment into this industry.

6 ACKNOWLEDGEMENTS

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Colin Grassie is a Teaching Fellow in Music Technology at the University of the West of Scotland (UWS). From a background as an electrical engineer moving into audio engineering he graduated from the School of Audio Engineering in 1992 and Glasgow Caledonia University with a degree in Music Technology with Electronics in 1996. Initially working in audio systems installation and freelancing in live sound he then became a lecturer in Further Education in 1997. He has authored in "sound production" for the Scottish Qualifications Authority (SQA) and contributed to national curriculum design. Since joining the UWS in 2009 he is primarily involved in teaching studio production, electroacoustics and practical room acoustics with an interest in spatial audio. As a Fellow of the Higher Education Academy, he has a vested interest in developing education practice for aspiring audio professionals.

Fraser Clark joined UWS in 1990 as lecturer in Optics, then Senior lecturer 1998 and Reader in 2001 after spending 5 years as a PDRF at University of Strathclyde, Dept. Electrical and Electronic Engineering. Currently he is the discipline lead for Music and Animation and his teaching interests have ranged from Optics, Electronic Design, Communication Theory, Embedded Systems, and Sensors to Acoustics and Audio Signal Processing. He has over 40 papers published in a diverse range of journals and conferences reflecting the range of interests and regularly performs development work for SMEs under a variety of Government sponsored schemes such as KTP. Dr Clark has won several prizes for technological innovation, SMART 2001, John Logie Baird 2000 and is a member of the Institute of Engineering and Technology.